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Low-cost Educational Robotics (LCER) Design Framework

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Low-cost educational robotics (LCER) design framework (Research/Curriculum Exchange)

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This Pre-College Engineering Education (PCEE) Division Research/Curriculum Exchange Paper presents the Low-cost Educational Robotics (LCER) framework. As engineering, computer science, and robotics opportunities continue to grow within education, equitable devices can support under-resourced schools (e.g. Wedeward & Bruner, 2002; Zhu et al., 2024). Robotics engages students with technology, engineering, and computer science in a meaningful way (Benitti, 2012; Ntemngwa & Oliver, 2018), providing opportunities for embodied learning (Zheng et al., 2024), and alternatives to screen time (Sullivan et al., 2015). As schools build robotics programs, the cost of robotics and electronic devices can be a barrier to offering students the opportunities (Ahmed & La, 2015; Venkatesh, et al., 2021). Low-cost engineering frameworks for robotics typically center industrial or higher education institutions with larger budgets and more internal support than K-12 institutions (i.e., Pedra et al., 2014). Designing robotics for K-12 education requires knowledge about the context and resources of schools.

The LCER framework is for designers of educational robotics to consider the needs of schools, affording access to technology. To create the LCER framework, we adapted existing engineering robotic design and educational technology frameworks. Many low-cost robotics projects (e.g., Murali et al., 2019; Tsalmpouris et al., 2021) developed for research are not easily scalable, are relatively expensive, or require specific technical knowledge. Educational technology frameworks that evaluate the use of technology in schools often focus on existing technology (e.g., Marangunić & Granić, 2015; Moro et al., 2023). We seek to combine principles in these frameworks by considering the technology and curricular needs of educators for designing low-cost educational robotics.

The components of the LCER framework describe the trade-offs associated with low-cost electronics (e.g., plastic-geared motors, STM32F0 microcontroller), use of open-source tools (e.g., KiCAD, GCC), manufacturing and distribution options (e.g. educational kits, digital fabrication tools) serviceability (e.g., 3D-printed part repositories, troubleshooting guides), software options (e.g. Python, MakeCode), and curricular support (e.g. tutorials, guided lesson plans) to design low-cost robotics. Rationale for the inclusion of each framework component is included from a larger project in which both teachers in under-served communities and experts in robotics were surveyed about implementation and cost of robotics in schools.

Here we share how the LCER framework (Table 1) could be applied through an existing, low-cost educational robotics project, Roversa (Bredder, 2024). This project was initially designed using parts of the Educational Robotics Application framework (Catlin & Blamires, 2010), and we share how the lessons learned in the design and implementation of the Roversa project are applied in this framework. The framework was developed from the design of Roversa and insight from educational robot developers and technology and CS educators. The open-source robot, Roversa, consists of common components, laser cut and 3D-printed parts, a printed circuit board designed in open-source software, and curriculum support for teachers. This serves as a practical example of building the LCER framework (Figure 1).

Implications of the LCER framework include providing educational robotics to schools that may not have the resources to purchase and continue to support robotics in K-12 education. For example, the framework can be used to help designers weigh tradeoffs between design decisions to ensure functionality against cost throughout prototyping stages. Our next steps for applying and researching the effectiveness of the framework is to look at each of the tradeoffs in each of the categories through applied testing. We are currently testing hundreds of servo motors, documenting their parameters to pair them accordingly. The cost of the motor is cheap, but the motors are not all consistent. The LCER framework will also enable robotics designers to consider K-12 educational contexts to support teachers in standardizing practices for co-design in educational robotics. For example, the framework can be used to conduct future research studies in the co-design of educational robotics for the classroom to enable communication between engineers and educational stakeholders who use these technologies with students. This framework will then support the transition of designing affordable robotics technology from research to practice in K-12 education.

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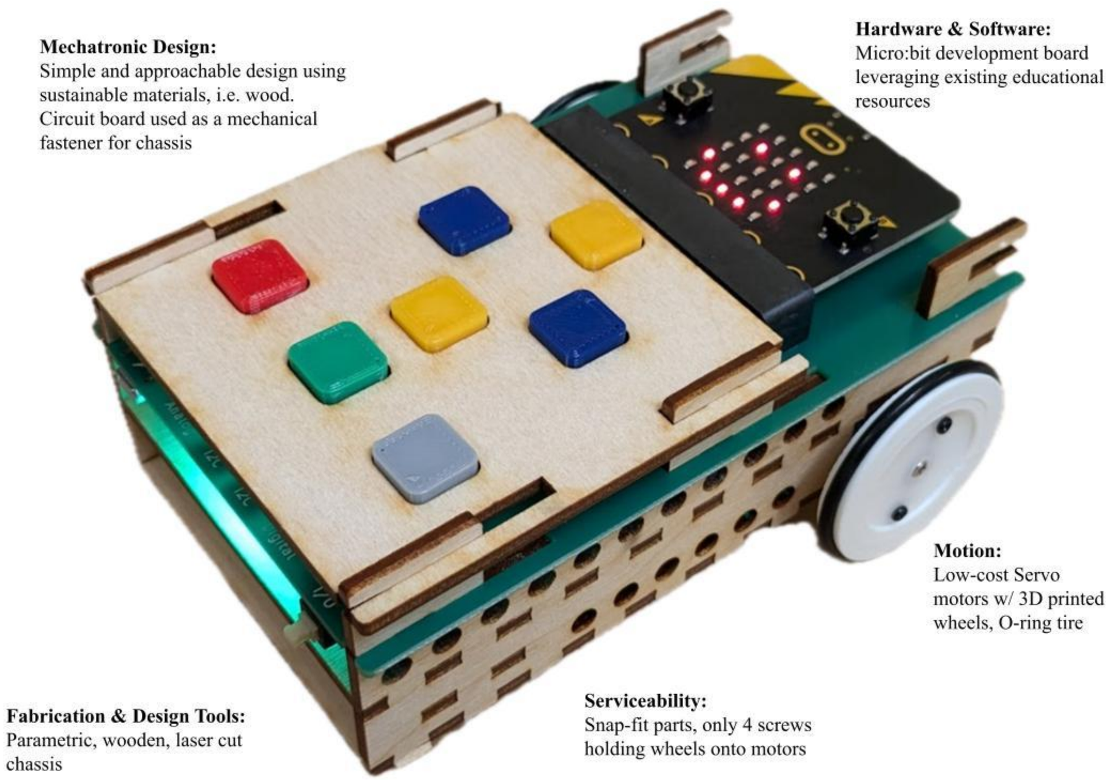
Table 1. Low-cost educational design (LCER) framework

Technology	Description	Tradeoffs	Example
Mechatronic Design	Electronic and mechanical components of a robot that work together to form the physical robot	Material costs, overall design to form chassis and hold components	Chassis material, flatpack design, hardware (nuts/bolts) selection, motor mounting solutions
Motion	Control of the motion aspects of the robot i.e. driving, linear movement, articulation, etc.	Accuracy, calibration methods, motor drivers, speed/torque	Driving, articulation, movement, linear motion
Fabrication & Design Tools	Selection of tools to support the development of the robot	Contract manufacturing, in-house design, consulting, desktop fabrication tools, assembly	Laser cut chassis sheet, parametric design to adjust for inconsistencies in lower cost materials
Serviceability	Ability to easily troubleshoot, repair, and recreate components	Design decisions lend towards the ability to swap parts and fix robot in educational setting without having to fully replace the robot or require technician support	Snap fit parts, documentation, open source design files
Hardware & Software	Choice of microcontrollers and tools to program the robot for specific functions	Cost of electronic components/microcontrollers,	Using existing development boards with educational support and software, open-source toolchains
Curricular Support	Providing materials for educators to use the robot in their classroom	Designing curriculum and lessons takes expertise, support, content, time, and implementation with robot	Lesson plan repository linked with CS standards

Figure 1. LCER Framework applied to Roversa, a low-cost, open-source educational robot.



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